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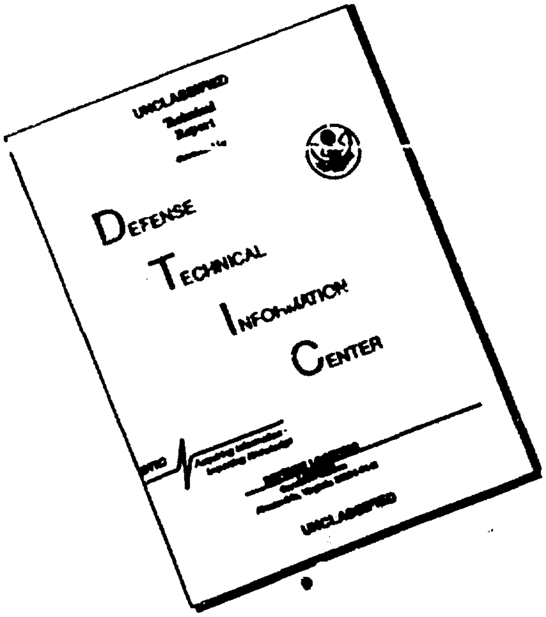

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DIRECT MEASUREMENT OF TURBULENT HEAT FLOW IN THE SURFACE LAYER OF THE ATMOSPHERE

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The turbulent heat flow plays an important role in the thermal balance of the surface layer atmosphere and the THF (Turbulent Heat Flow) and is one of least studied components of the thermal balance, which is due to a series of difficulties in methods, with which one is confronted in such measurements. Up to the present time the importance of THF has been defined generally by indirect methods, which do not give sufficiently exact results. The majority of calculation formulae have been determined with an accuracy up to constant coefficients or universal functions, the finding of which is possible only from experimental data on direct measurements of the THF. Direct measurements of the THF [1.5] are based on the use of the well-known equation.

$$q = \rho c_p \overline{T'W'}$$

where q = THF; ρ = density of the air; c_p = thermo-capacity of the air at a constant pressure; T' and W' = deviations of respectively temperature and the vertical component of the wind velocity from their mean value; the prime indicates an averaging in time.

Such measurements were conducted by means of the simultaneous recording of the instantaneous values of air temperature and of the vertical component of wind velocity followed by a laborious processing of the results. Either thermo-elements [5] or resistance thermometers [2] were employed as a temperature data unit. The defect of the measurement systems employed was the need for frequent zero calibration of the instrument, caused by variations in the mean air temperature during the measurements. For measurements of the vertical component of wind velocity thermo-anemometers, [3] anemometers using heated thermo-elements [5] and other devices were employed. The basic deficiencies of these instruments were the non-linearity of their calibrated

characteristics, the relatively great inertia and dependence of calibration on the magnitude and direction of the average wind velocity. The non-linearity of the vertical velocity data units renders automation in the calculation of the mean product difficult. The time-consuming nature of the processing of measurement result recordings gave rise to a limited selection of experimental data and a small averaging period. Thus, in work (1) the averaging time was 30 seconds, which, as will be shown below, is insufficient.

In 1957-1958 at the Acoustical Laboratory of The Institute of Physics of the Atmosphere of The Academy of Sciences, USSR, a new method was devised for the direct measurement of the THF and preliminary THF measurements were conducted. The general diagram of the measurements is shown in figure 1.

The pulsations of the vertical component of wind velocity W' were measured by means of an acoustical micro-anemometer, (4) the operational principle of which is based on the measurement of the propagation time of a sound wave in air which, using fixed microphones as a point of reference, is in motion. The micro-anemometer has two 2-millimeter radiators and two microphones similar in design. In order to measure W' the radiators and microphones were placed on a vertical plane at a distance of 2.5 cm one from the other. The frequency of the uninterrupted supersonic oscillations, on which the measurements were conducted, was 75-100 cps. The magnitude and sign of W' were determined by the phase shift of the audio wave reaching the microphone. The sensitivity of the micro-anemometer is 9 cm/sec x wind velocity and does not depend on mean wind velocity. The output voltage is linearly dependent on the wind velocity measured; the range of the instrument is ± 2m/sec. The micro-aneometer measures, without distortion, wind velocity pulsations in a frequency range from 0-700 cps. Noise generated by the

instrument itself did not exceed (in terms of wind velocity) 1 cm/sec. The acoustical circuit excluded the possibility of the influence of temperature pulsations on the wind velocity measurements.

For the measurements of temperature fluctuations a pulsation resistance-type thermometer with a data unit in the form of a 20-micron platinum wire, 20 mm in length connected to a bridge circuit, was used. The time-constant of such a data unit is, according to (3), in the order of 0.01 seconds. Parallel to one of the arms of the bridge was connected a thermo-resistor with indirect heating. The thermo-resistor is heated by current in the negative feed-back-circuit of the bridge-unbalance-voltage-amplifier. An integrating RC circuit with large time constant is connected to the negative feed-back circuit. Thanks to this negative feed-back circuit, the thermometer "zero" is able to track variations in the average air temperature in a smooth fashion (with a time-constant of more than 100 sec). When measuring temperature pulsations with a thermometer of this kind there is no longer any need to adjust the instrument during measurements.

The maximum sensitivity of the thermometer is 0.15°C/wind velocity, the amplitude characteristic is linear (for pulsations) within ±2°. Thermometer noise is less than 0.01°. In this way high sensitivity is provided in the thermometer to pulsations over a broad range of mean temperature measurements.

The voltages U_1 and U_2 obtained at the output of the micro-anemometer and the resistance-type thermometer are proportionate respectively to the instantaneous values of vertical component of wind velocity $U_2 = k_1 W'$ and to the temperature pulsations $U_2 = k_2 T'$. These voltages reach the two in-

puts of a correlometer, an electronic device, on the output of which current I is proportionate to the product, average in time, of the two input voltages $I = k_3 \overline{U_1 U_2}$. This current is measured by an arrow-type indicator, the scale of which may be calibrated directly in THF values: $q = k_4 I = k_5 \overline{W' T'}$.

At the sensitivities indicated above for the micro-anemometer and pulsation-thermometer and at maximum sensitivity of the correlometer the multiplying factor of its output device was 0.02 cal/cm^{2}x min. The product of the instantaneous values $U_1 U_2$ is averaged with an integrating RC circuit with a time constant of 100 seconds. The micro-anemometer and pulsation thermometer data units were fastened jointly to a remote head (Fig 2) in such a way that the distance between the data units was about 3 cm. In September 1958, a series of direct THF measurements was carried out. The measurements were conducted on a flat area 700 x 600 meters in extent on an open plain and were accompanied by temperature and wind profile measurements in altitude. On the basis of the results of the gradient measurements, the Richardson numbers Ri were calculated.

Parallel to the THF measurements, there were carried out measurements and statistical analyses (by means of spectrum and distribution analyzers, specially designed for these purposes) of temperature pulsations and wind velocity components. The RMS values, obtained as a result of the processing of the pulsation measurements, for fluctuations in temperature and the vertical component of wind velocity ($\sqrt{\overline{T'^2}}$ & $\sqrt{\overline{W'^2}}$), together with the heat flow values $q = k\,\overline{W'T'}$, made it possible to calculate the correlation coefficient $r_{W'T'}$

$$r_{W'T'} = \frac{\overline{W'T'}}{\sqrt{\overline{T'^2}}\sqrt{\overline{W'^2}}}$$

The heat flow was measured alternately at heights of 1 and 4 meters; in all 360 measurements of q were conduced at a height of 1 meter and 80 measurements at 4 meters. The measurements were conducted with 2-minute intervals. A processing of the measurement results showed that a 100-second averaging, to which each individual measurement corresponds, is insufficient, since in this case the q values are found to be unstable. It was discovered that in order to obtain stable q-values, averaging is necessary about 10 minutes, as may be seen from the diagram in Fig 3.

A comparison of the correlation coefficients $r_{W'T'}$ with corresponding (in time) Ri numbers, which is shown Fig 4, indicates that as the instability increases ($Ri \rightarrow -\infty$) the correlation $W'T'$ also rises. Physically this is completely understandable, since with the rise of instability convection begins to play an ever greater role in heat transfer.

Although simultaneous q measurements at heights of 1 and 4 meters were not conducted, nevertheless on the basis on the results achieved it may be said that q values at these two heights are extremely close. The mean value of the relation of these values q_4/q_1, obtained by 14 values for q_1 and q_4 measured at identical times of the day, equals 1. This is in good agreement with theoretical considerations from which it follows that the turbulent heat flow must not change with altitude. Let us note that when determining the heat flow by indirect methods differences in the value of q at various heights are quite substantial.

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CAPTIONS

Figure 1 General diagram of the measurement of turbulent heat flow.

1. Pulsation thermometer data unit.
2. Micro-anemometer data unit.
3. Amplifier and micro-anemometer phasecmeter.
4. Pulsation thermometer amplifier
5. Correlometer

Figure 2 Remote head of micro-anemometer and pulsation thermometer.

1. Microphones
2. Radiators
3. Pulsation thermometer data unit

Figure 3 Time path of THF on 7 September 1958

1. 100 second averaging
2. 10 minute averaging

Figure 4 Dependents of correlation coefficient $r_{w'T'}$ on Ri number.

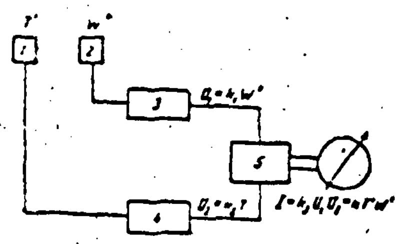

Рис. 1. Общая схема измерения турбулентного потока тепла. *1* — датчик пульсационного термометра, *2* — датчик микроанемометра, *3* — усилитель и фазометр микроанемометра, *4* — усилитель пульсационного термометра, *5* — коррелометр

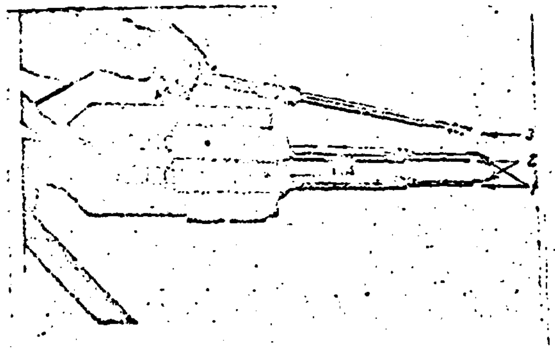

Рис. 2. Выносная головка микроанемометра и пульсационного термометра. *1* — микрофоны, *2* — излучатели, *3* — датчик пульсационного термометра

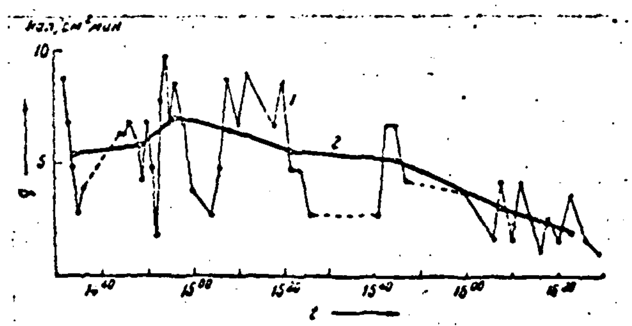

Рис. 3. Временной ход т. п. т. 7 IX 1958 г. *1* — осреднение 100 сек., *2* — осреднение 10 мин.

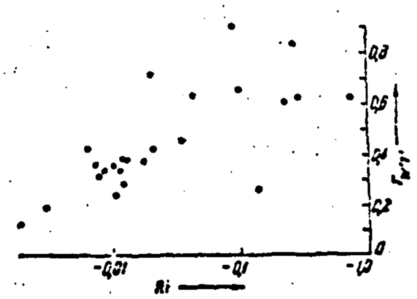

Рис. 4. Зависимость коэффициента корреляции $r_{w'\tau'}$ от числа Ричардсона Ri

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